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13. ABSTRACT (Maximum 200 words)

This report results from a contract tasking University of Siegen as follows: The contractor will investigate low cost Single Event Upset (SEU) radiation flight experiment using state-of-the-art low voltage Static Random Access Memories (SRAMs).

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PARTICLE UPSETS IN MEMORY ARRAYS (PUMA)

Final Report, June 1999

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SUMMARY

A low cost Single Event Upset (SEU) radiation flight experiment was performed for low voltage Static Random Access Memories (SRAMs). Non-volatile battery powered memory types were used which did not need any power or line connections to the flight carrier. This low cost, low mass and low volume experiment offers a 'per flight' way of assessing neutron induced SEUs in modern semiconductor technologies. A hardware and software system was developed to program, read and test the memory devices. SRAMs were exposed to the radiation in the upper atmosphere during flights of the WB-57F aircraft starting from Ellington Field, Houston, during some commercial flights and to radiation fields at different particle accelerators. The in-flight behavior of the devices is compared with the results of predictions using latest environmental models and ground test data.

EXPERIMENTAL TECHNIQUE

Flight hardware

Before starting the project large effort had been put into the selection of suitable SRAM types for flights. Ground SEU testing, covering both protons and neutrons, are behind the SRAM selection and a number of PUMA transatlantic flights (as hand luggage) have confirmed avionics SEU to occur. It is of particular importance that flight results, ground testing and technology information are coming from the same memories (mask set - date code), issues which are often lacking when flight and predicted behavior are assessed. The final PUMA flight experiment consist of a number of commercially available non-volatile memory devices which are placed on PCB and protected by a suitable box. The box has a size of (4 x 5 x 10 cm^3) and contains 10 memory devices with 4 Mbit each. We used the Dallas DS1650Y.70 SRAM, the 4 Mbit type, organized as 524288 words by 8 bits, with a self-contained lithium energy source. This type conforms to the 32-pin DIP

standard with dimensions of 44 x 18.5 x 14 mm. Modules of 10 devices require a volume of 120 x 65 x 42 mm and a weight of about 260 grams. Four of these boxes, each containing 40-Mbit of memory, were made available as PUMA flight experiment. The memory devices have been supported by ESTEC.

Device programming and testing

The first work package of this project was to install equipment for programming, reading and testing of the devices. A system was developed under responsibility of the University of Siegen. Part of the programming was done by ELBEK, a contractor at Siegen. Different device programmers have been tested. Finally a very simple and inexpensive programmer, the Needham EMP10 was used. This programmer is connected to the printer port of a PC.

A computer code (PUMA.EXE) communicating with the user under WINDOWS 95 operating system has been developed. It uses the EMP10 (EMP10.EXE, working under DOS environment) to

- write bit patterns into the memory,
- read out bit patterns from the memory after the flight,
- and compare the bit patterns as a test for single event upsets.

The results of the analysis are stored in files that may be exchanged between Ellington field, ESTEC at Noordwijk, Netherlands and Siegen, Germany by e-mail. Three hardware versions of this system are available. Two remained at Siegen and one, a 110 V version, was brought to Ellington field to be used during the PUMA flights on board of the WB-57F aircraft.

Details describing the hardware, the software and the operation of this system are given in the PUMA.EXE manual.

Preparation of flight experiments

Before a flight the memories were loaded with distinct bit patterns. Performing an experiment means to fly the module containing the memories and to check their content when returning. This approach allows to assess neutron induced upsets in aircraft. The result for the specific conditions of one flight is the overall SEU number, the addresses of the upset bits, the upset sensitivity for transitions 0 to 1 and vice versa. After the flight the memories were read and checked for SEUs using the PC based programming and reading device. Flight data as time, geographical position and flight altitude have to be stored together with the SEU-data for later analysis.

On March 16 1998 an experimenter's meeting was held at Ellington Field with Shelley Hilden from NASA, Brian Carpenter from Rome Laboratory and Wolfgang Heinrich from University of Siegen participating. The memory programming and test system and three PUMA experiment boxes each one containing 10 memory devices were delivered to S. Hilden. Details of the operation of the programming device were discussed and exercised. A procedure of

documentation and transmission of the experimental results and the navigation data was discussed and agreed on.

The following tasks should be carried out at Ellington Field as support of this experiment:

Preparation for flight (typically 30 min. exercise):

1. Open the PUMA box (4 screws)
2. Remove all memories and program each device by using the portable PC programmer/reader (following instructions described in the manual)
3. Re-position all memories and close box (ready for flight!)

Post flight testing (30 min. exercise):

1. Open the PUMA box (4 screws)
2. Remove all memories and read each device by using the portable PC programmer/reader (following instructions described in the manual)
3. Re-program memories (Preparation for next flight)
4. Re-position all memories and close box (ready for flight!)
5. Forward by e-mail results to Siegen/ESTEC

ACCELERATOR EXPERIMENTS

In the preparation phase of this experiment and also during the operational phase several tests were performed using accelerator beams. These experiments support some fundamental data with high statistical significance. During an ESTEC test campaign in November 1997 at the OPTIS (low energy) proton accelerator at PSI Villigen, Switzerland the cross section for proton induced upsets was measured at different energies. Additionally an exposure of the devices to 180 MeV neutrons was performed in March 1998 at the accelerator facility at Uppsala, Sweden. In April 1998 and again during June 1999 the CERF facility at the European accelerator center CERN, Switzerland had been used. This provides radiation fields comparable to those of the upper atmosphere. Details of the exposure conditions and results of these accelerator runs are summarized below.

Irradiation at PSI Villigen, Switzerland

At the PSI beam line OPTIS, equipped for testing of electronic components during a standard test campaign of ESTEC, a PUMA box containing 8 devices of the DS1650Y.70 was irradiated with $5\ 10^{9}$ protons/cm^{2} at a rate of approximately $5\ 10^{17}$ per second at different energies. Details of this test, beam energy, number of observed upsets and derived cross sections are presented in table 1.

Table 1: Results of the proton exposure at PSI, November 1997

device number	proton energy MeV	number of upsets per device	device cross section cm^2
A3	10.9	failed	
A6	10.9	13	$(2.6 \pm 0.7)\ 10^{-9}$
A4	15.0	failed	
A7	15.0	9	$(1.8 \pm 0.6)\ 10^{-9}$
A5	22.8	22	
			$(3.8 \pm 0.6)\ 10^{-9}$
A9	22.8	16	
A8	43.8	failed	
A10	43.8	2785	$(5.6 \pm 0.1)\ 10^{-7}$

Irradiation at CERN April, 1998

At the European accelerator center CERN at Geneva, Switzerland, an irradiation facility in mixed high energy particle fields produced by interactions of particle beams has been established. A beam of 205 GeV/c positively charged particles (about 2/3 protons and 1/3 pions is shot at the center of a cylindrical copper target (50 cm length, 7 cm diameter). This target is located under a 80 cm thick concrete roof shield. The stray fields on top of this concrete target contains different types of particles with different energies produced in nuclear cascades generated by the beam particles in the set up. The idea is to produce at this test place particle fields, which are comparable to the particle fields in the atmosphere produced by the primary comic radiation. These radiation fields were calculated using the FLUKA code and also measured in some experiments. Figure 1 shows the neutron spectrum measured on top of the concrete (toc) by Schraube et al. (1999) in comparison to calculations using FLUKA (Birattari et al. (1998)). It was possible to expose a PUMA box during two runs at this facility.

The PUMA memory box was exposed in field CT1 on top of the concrete. The box was irradiated for a total of 97902387 PIC counts. Each PIC corresponds to $(2.2 \pm 0.2)\ 10^4$ protons incident on the target (copper). The neutron fluence rate is $3.63\ 10^{-5}\ cm^{-2}$ per incident proton. This means that the devices were exposed to a total fluence of $7.8\ 10^7$neutrons cm^{-2}. The number of upsets observed is listed in table 2:

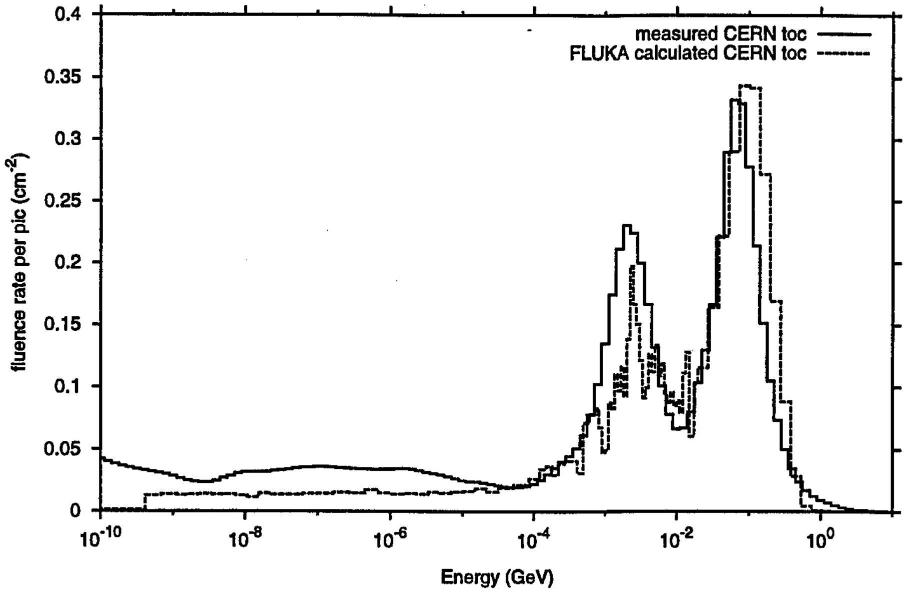

Figure 1: Neutron spectrum measured on top of concrete in comparison to a calculated spectrum based on the FLUKA code. The y axis represents the spectral fluence Φ_E multiplied by the neutron energy. In this plot equal areas correspond to identical numbers of particles.

Table 2: Results of the exposure at CERF/CERN, April 1998

device number	number of upsets per device
B27	failed
B26	25
B25	20
B24	failed
B23	19
B22	19
B21	22

As a mean value 21.00 $\pm$ 2.05 upset were observed per device in this exposure. As a result one gets 2.96 $\pm$ 0.29 10^{-7} upsets per device for 1 neutron cm^{-2}, i.e. a device cross sections of 2.96 $\pm$ 0.29 10^{-7} cm^2.

Irradiation at CERN, June 1999

The PUMA memory box was exposed in field CT13 on top of the concrete. The box was irradiated for a total of 42119999 PIC counts. Each PIC corresponds to (2.2 ± 0.2) 10^4 protons incident on the target. The neutron fluence rate is 3.63 10^{-5} cm^{-2} per incident proton. This means that the devices were exposed to a total fluence of 3.36 10^7neutrons cm^{-2}. The number of upsets observed is listed in table 3.

Table 3: Results of the exposure at CERF/CERN, June 1999

device number	number of upsets per device
B27	failed
B26	9
B25	10
B24	8
B23	16
B22	7
B21	8

As a mean value 9.67 ± 1.03 upset were observed per device in this exposure. As a result one gets 2.88 ± 0.30 10^{-7} upsets per device for 1 neutron cm^{-2}.

These results are within their statistical errors in excellent agreement with the April 1998 results. The fact that results of both experiments are consistent and allows to combine the data. For a total exposure to 10.46 10^7 neutrons cm^{-2} we get a value of (2.8 ± 0.2) 10^{-7} upsets per device for 1 neutron cm^{-2}.

Irradiation at Uppsala, March 1998

One PUMA box containing 7 memory devices was exposed to a neutron beam at the accelerator at Uppsala, Sweden. These neutrons were produced from a proton beam of 180 MeV hitting a target. As a result neutrons having almost the initial proton energy are produced. Simultaneously neutrons with a wide spectrum of energies extending down to very low energies are generated. The high energy neutrons account for about half the neutron fluence. The PUMA box was exposed to a total fluence of 2.5 10^7 neutrons cm^{-2}. The number of upsets observed is listed in table 4.

As a mean value 28.14 ± 2.00 upset were observed per device in this exposure. As a result one gets (1.13 ± 0.08) 10^{-6} upsets per device for 1 neutron cm^{-2}.

Table 4: Results of the neutron exposure at Uppsala, March 1998

device number	number of upsets per device
B27	29
B26	14
B25	33
B24	34
B23	39
B22	20
B21	28

FLIGHT EXPERIMENTS

Air Canada flight Frankfurt to Calgary and return

The flight hardware was ready end of 1997. It could be tested before the complete assembly of the programming/reading hard/software using a preliminary version of this set up. Three PUMA boxes, each one containing ten memory devices were flown on Air Canada flight 845 to Calgary on November 21 1997 and return to Frankfurt on Air Canada flight 844 on November 26 1997. The crew of both flights was very helpful and supported us with the flight data in form of altitude and position as a function of time. After the flight one device showed one upset bit, two devices failed completely. The neutron fluence calculated based on the flight profile and the cosmic ray model for the total exposure on both flights is $2.2\ 10^5$ neutrons cm^{-2}.

As a mean value 1/28 upsets were observed per device in this exposure. As a result one gets $(1.6\ +3.7, -1.3)10^{-7}$ upsets per device for 1 neutron cm^{-2}.

WB-57F test flights April 1998

Details of upcoming flights were discussed with the flight test engineer at Ellington Field, Shelley Hilden, JSP in the meeting held there in March 1998. It was planed to mount the PUMA boxes of size 4 x 5 x 10 cm^3 in a map case in the rear cockpit. The WB-57F aircraft was going to start functional check flights after a 6 month maintenance period. These flights were used for first tests of the PUMA experiment. We were aiming at an aerosol mission that should be flying sometime in March or April 1998 at northern latitudes (low geomagnetic cut-off rigidity) and at high altitude for a long duration.

During four short duration test flights of the WB-57F aircraft between March 23 and April 9 the three PUMA memory boxes were flown altogether for approximately 10 hours at an altitude

above 30000 feet. After these flights 4 out of the 30 devices flown did not show the expected bit pattern. One device was corrupted completely, one device was not usable due to a programming error and two showed one single bit changed after the flight. This results in an integral upset rate of two bits in 28 devices. The neutron fluence calculated based on the flight profiles and the cosmic ray model for the total exposure on both flights is $9\ 10^4$ neutrons cm^{-2}.

As a mean value 2/28 upsets were observed per device in this exposure. As a result one gets (7.9 +10.4, -5.1) 10^{-7} upsets per device for 1 neutron cm^{-2}.

To get results with higher statistical significance, it was planed to fly the three memory boxes on all upcoming missions of the WB-57F until an integral flight time of about 100 hours would be accumulated. These flights were expected to be running until end of June 1998. The idea was to collect data after this during the next 12 months under specific conditions with respect to geomagnetic shielding covering different cut-off rigidities and different flight altitudes if possible. These data have not been provided so far.

Concorde flights

A PUMA box, containing seven memory devices was flown on eight return flights from London to New York in February 1999. After the flights five devices showed completely corrupted memory contents. Two devices showed the original bit pattern. The Puma box had been opened to inspect the content before the flight. This may explain the high rate of not operating devices. The calculated neutron fluence based on the flight profile and the cosmic ray model for the total exposure on both flights is $2.0\ 10^5$ neutrons cm^{-2} for one return flight. For the eight flights and the two operating devices based on a cross section of $2.79\ 10^{-7}$ upsets per device for 1 neutron cm^{-2} determined in the CERN experiment the expected number of upset bits is 0.57, which is in good agreement with the observed number of no upset.

COMPARISON AND ANALYSIS OF THE RESULTS

Neutron fluence for devices exposed in flight experiments

This project aims to study the variation of the upset rate with flight parameters in correlation to calculated neutron spectra in the atmosphere. The theoretical model of neutron fluxes in the atmosphere has already been developed and published (Roesler et. al.(1998)). This knowledge can be used in a SEU prediction model for different flight conditions of the experiment.

Figure 2 shows a calculated energy spectrum of neutrons for a flight altitude of 37500 feet. This was determined based on the FLUKA code using the method described by Roesler et al. (1998). The calculation has been performed for the situation of minimum solar activity considering the geomagnetic shielding of polar regions with a cut-off rigidity of 0 GV. Calculations for situations of different geomagnetic shielding (cut-off rigidities varying from 0 GV to 17 GV), different primary cosmic ray energy spectra representing solar modulation at solar maximum and solar minimum and for different flight altitudes have shown that the shape of this spectrum is constant.

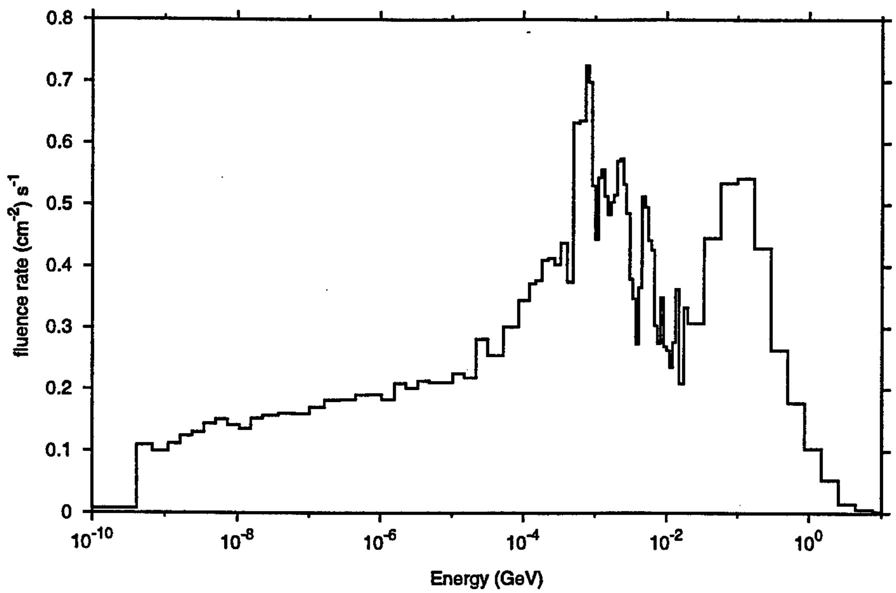

Figure 2: Calculated energy spectrum of neutrons for a flight altitude of 37500 feet.

With the same model fluence rates (neutrons cm^{-2} s^{-1}) have been determined for different cut-off rigidities. Based on these data the neutron fluence to which a device has been exposed in a flight can be calculated. For this purpose the position and altitude dependent calculated fluences are summed up based on the specific flight data. The flight specific neutron fluence rates used above were determined by this procedure.

A detailed comparison between model predictions and experimental results, which would allow to find week points of the model, to define dedicated experimental conditions and to help to develop the model further has not been possible until now based on the limited flight data available at Siegen. However, the method and analysis software for this purpose has been developed. It should be a minor task to perform this analysis, if all data collected at Ellington field would be supported.

Complete loss of memory

In all flight and accelerator experiments for a few devices a complete (or almost complete) loss of memories was observed. In almost all cases the devices had been transported to the place of irradiation in commercial flights as hand luggage. We have performed an experiment to exclude effects caused by safety inspection. A PUMA box was exposed at the Köln-Bonn airport to multiple x-ray safety inspection. After even multiple inspection no device showed any effect. Additionally complete memory loss has been observed for one device which had been programmed and analyzed at Ellington field without any x-ray inspection. Based on these observations it can not be excluded, that a complete loss of memory may be caused by radiation effects.

Comparison of in flight results and results of the accelerator experiments

The SEU cross sections resulting from the different accelerator exposures and flight experiments are compared in figure 3. At an energy below 25 MeV the cross section for proton induced SEUs is below 10^{-8} cm^2. It increases to a value of 5.6 10^{-7} cm^2 above 40 MeV. This energy dependence with a cross section increasing with energy to a saturation level is typical for proton exposures. For the Uppsala 180 MeV neutron beam, the neutron fields at the CERN facility and for the different flights cross sections above 10^{-7} cm^2 were observed. These data are consistent with each other, however a more detailed analysis would require more detailed data from the WB-57F flights.

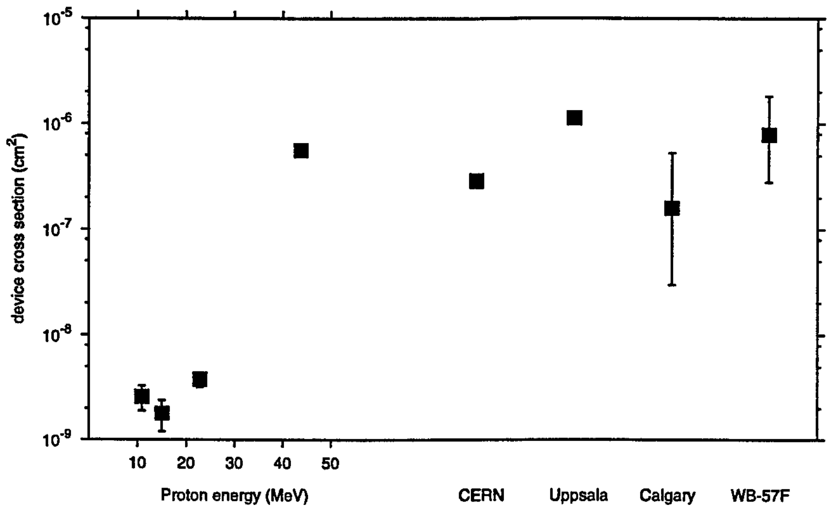

Figure 3: SEU cross section for the Dallas DS1650Y.70 SRAM measured for protons of different energy, for the CERF field at CERN, for a 180 MeV neutron beam at Uppsala, for a commercial flight from Frankfurt to Calgary and for WB-57F test flights.

CONCLUSIONS

- A simple, low cost, low mass and low volume flight experiment to study SEUs in SRAMs has be performed.

- It has been shown, that this type of experiment is suited to collect valuable in flight data.

- Experiments at different accelerator facilities have supported some fundamental data with high statistical significance.

- Data collected in different flights are in good agreement with predictions based on the accelerator results and calculated neutron fluence at flight levels.

- This study could really be a great success if the data expected from the WB-57F flights could be made available for the analysis.

REFERENCES

Roesler, S., Heinrich, W., Schraube, H., *Calculation of Radiation Fields in the Atmosphere and Comparison to Experimental Data*, Radiation Research **149**, 87-97 (1998)

Schraube H., Mares, V., Roesler, S., Heinrich, W., *Experimental verification and calculation of route doses,* In press in Radiat. Dosim. 1999

Birattari, C., Ferrari, A., Höfert, M., Otto, T., Rancati, T. and Silari, M., *Recent results at the CERN-EC high energy reference field facility.* Proceedings of the Third Specialists Meeting on Shielding Aspects of Accelerators, Targets and Irradiation Facilities, Sendai, Japan, 12-13 May 1997, OECD-NEA, 219-234 (1998)

PUMA.EXE Version 1.0

The program is designed to read and write a special type of memory device (DALLAS 1650Y) which is used to study particle induced upsets in memory arrays (PUMA). The devices are static random access memories with internal backup battery and additional write protection circuit.

1. HARDWARE DESCRIPTION

The main program, PUMA.EXE, uses a commercially available programmer (type Needham's EMP10) for input / output of data to / from the memory device. The programmer is connected to the computer's printer port. Therefore it is sometimes necessary to remove special printer drivers (for example HP Laserjet 5L) from the system when using the EMP10. The programmer is powered by an external supply.

The device to be tested or to be written must be inserted into the socket (a so-called zero input force dual in line socket ZIF) of the EMP10. Before inserting or removing a device from the socket, the lever on the bottom of the socket must be pushed upwards to open it. The memory must be placed in that way that pin 1, which is marked with a dot, points to the opposite side of the lever. The other side of the device must be aligned with the side of the lever. After inserting the device into the socket it is fixed by lowering the lever.

WARNING : When inserted in the false direction the device will be permanently damaged.

On the left side of the ZIF socket there is a family module which should always read as M1B at the bottom. This module must not be removed or replaced.

2. HARDWARE INSTALLATION

- Shut down your computer
- Make a connection between the printer port of the computer and the programmer with the printer cable of the EMP10.
- Plug in the external power supply and connect the low voltage output to the programmer.
- Start the computer and disable printer drivers when necessary.

The procedure to disable the printer driver depends on the printer type. In most cases it is not necessary at all to change anything when using the EMP10 hardware, as the programmer directly accesses the printer port. Therefore only a malfunction of the programmmer may require changes to the system settings.

Sometimes when the printer was installed with a specific installation program there will also be a program to uninstall it. If no uninstall procedure is available the printer can be deleted from the system by selecting START/SETTINGS/PRINTER from the desktop. In both cases the printer should only be disabled when the procedure to enable it afterwards is known.

3. SOFTWARE INSTALLATION

- Create the directory 'C:\PUMA' on your harddisk.
- Copy all files on the disk to this directory

The files on disk are:

- EMP10.EXE	control program
- EMP10.INI	default data
- EMP10.IOP	port definition
- EMP10LIB.DAT	library for devices
- READ.INI	commands and definitions
- WRITE.INI	commands and definitions
- HISTORY.TXT	entries for all written files
- PUMA.JOU	log file of PUMA
- PUMA.HLP	help file for PUMA.EXE
- PUMA.EXE	main program

The .INI, .JOU, FLT, ERR, and .TXT files can be read into a text editor as they contain data in ASCII.

To make access to these files easier the extensions of the used files must be added to the system once. This is done by opening the EXPLORER and choosing VIEW and OPTIONS. In FILE TYPES the option NEW TYPES must be selected. In the dialog ASSOCIATED EXTENSION the ending of one of the used files (JOU, FLT, ERR, or TXT) has to be entered followed by ACTION NEW. As the application to be used with this file type choose NOTEPAD.EXE. This modification will allow to open the files with the editor by just clicking on it with the mouse.

4. SOFTWARE DESCRIPTION

The name of the execuable is PUMA.EXE. It runs under WINDOWS 95 operating system, while the control program of the programmer (EMP10.EXE) uses a DOS environment.

When started, the menu bar shows four entries: FILE, READ, WRITE, and COMPARE which allow to program a device (**WRITE**) to read out a device (**READ**) and to compare the bit pattern stored in a device with that one previously written into the device (**COMPARE**).The entry **FILE** allows to close the application PUMA.EXE.

All actions that are completed successfully (program start, program stop, writing a device, reading a device, and comparing device contents) are written to the log-file PUMA.JOU for documentation.

4.1 PROGRAMMING A DEVICE

To write a chip the operator has to select WRITE/START. This will open a dialog box for the required data (Fig. 1).

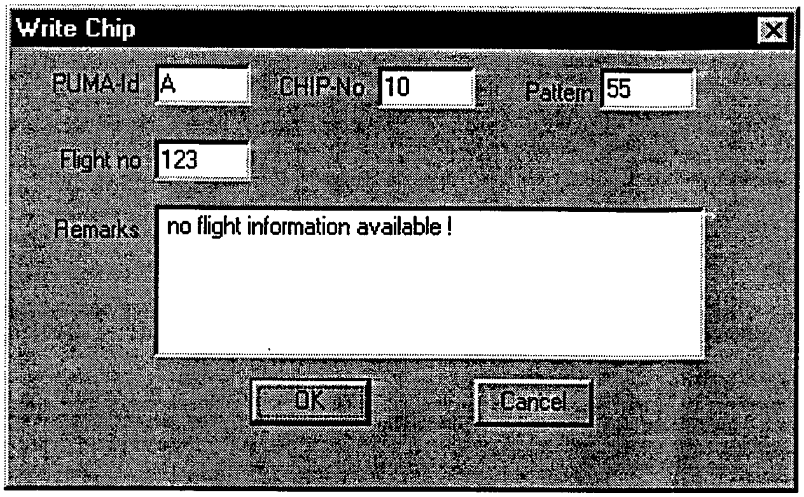

Figure 1: Dialog box of the WRITE function.

These data are:

- The identifier of the PUMA container, that will carry the device on the flight. The identifier is a single capital letter.
- The number of the chip as a two digit decimal value between 00 and 99.
- The bit pattern to be written. It has to be entered as a two digit hexadecimal byte. For example 55 as the default for the bit pattern 0101 0101.
- The flight number, which is currently defined as a decimal number with up to six digits.
- The remarks with flight specific data for flight description with a maximum lenght of 128 bytes. The remarks are saved in a file named : FN flight number . FLT.

After selecting OK a binary file will be generated by PUMA.EXE with a name that follows the convention: BoxID ChipNo DD MM Y Pattern . IN, where DD is the day in two digits, MM is the month, and Y is the last digit of the year. For example, writing chip number 10 of container A on the 21st of January, 1998 with pattern 55(hex) will produce the file 'A102101855.IN'.

Before writing a file to a memory device (for example A102101855.IN) it is copied to the transport file INFIL.DAT that is read by the control program EMP10.EXE and then written into the memory. This control program uses a procedure defined in a command file (READ.INI) to sequentially execute the commands necessary to program the device.

As programming is only possible when the devices are in the 'unprotected' state, the operator has to check the current state of the memory. This is done with the function 'B' of the control program. The state of all 16 memory blocks of the device will be displayed and the program waits for operator input. If all blocks are marked as 'unprotected' the user may only press escape (ESC) to proceed. If any block is marked as 'protected', the operator must use the keyboard

arrow keys (up / down) to select and (left / right) to change the state of any block to 'unprotected'.The function must be finished with RETURN (ENTER) to write the changes to the memory.

If both programming and the following verification of the contents succeeds, the control program EMP10.EXE is closed automatically. In case of an error it must be closed manually. The control program will display the message 'program verify error' and show the address of the error and the contents of both the data buffer and the memory. In order to return to the main program PUMA.EXE the operator has to press any key to close the message and then 'escape' (ESC) and 'YES' (Y). Typical errors during writing are caused by write protection of the memory devices and by failures when inserting the device into the socket (unclosed lever or misalignment).

After successful verification of the device the operator will be asked whether the data file should be added to the history file or not. In this file HISTORY.TXT the names of the files that were written into memory devices are saved until the devices are read and output files are generated.

4.2 READING A DEVICE

To read out the contents of a chip, the operator must select READ/START from the menu bar of the main program PUMA.EXE.

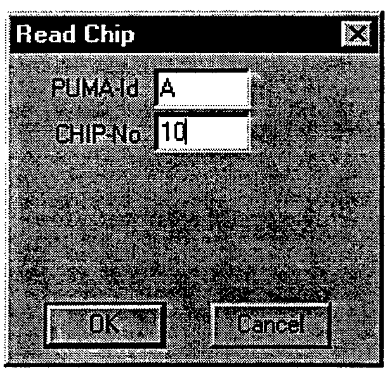

Figure 2: Dialog box of the READ function.

As reading only makes sense for devices thad have been written before, the user will only have to enter the container's identifier and the chip number of the device inserted in the socket (Fig. 2). From these data and from the contents of the history file the name of the output file is generated. The name will be the same as the input file with the extension '.OUT' instead of '.IN'.

After writing the ouput file the file name of the input file is removed from HISTORY.TXT. This will make it possible to write a new input file into the device for another experiment.

4.3 TESTING A DEVICE FOR UPSETS

The COMPARE/START entry of the menu bar starts the part of the program that, after input of the necessary data, checks the contents of the '.OUT' file against that of the '.IN' file for each byte.

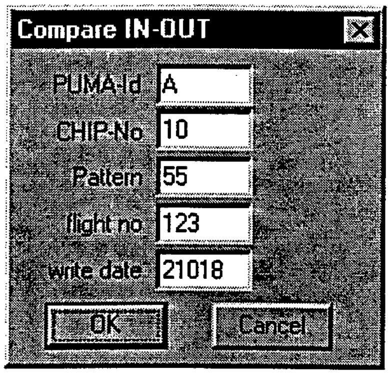

Figure 3: Dialog box of the COMPARE function

To match the file name convention the writing-date of the file must be entered as a 5 digit decimal value starting with two digits for the day, two digits for the month, and only one digit for the year. The above figure 3 shows the values for the example files A102101855.IN and A102101855.OUT.

All differences between the two files will be saved in an error file of the same name with the extension '.ERR'. This file will also contain in its first line the total number of bytes that are not identical in both files and the value given for the flight number.

All subsequent lines will contain the address of the mismatch as a 6 digit hexadecimal value, the value of the byte in the file written to the device (.IN), and the value of the byte in the file read back from the device (.OUT), both in hex.

As it is unusual to have a lot of errors in the experiments the number of errors is checked before writing the error file (.ERR). If the error count exceeds a certain number a warning message will be displayed and the operator will be asked if the error file is to be written. If the error count is in the order of 500000 this indicates that the chip is either completely damaged or improperly inserted into the socket. An error file of this type will be about 6 MB in size.